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Simulating Fine-Scale Atmospheric Processes: A New Core Capability and it's Application to Predicting Wildfire Behavior

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FY02 LDRD Project *Final Report*

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Final Report

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ABSTRACT

This LDRD project consisted of the development, testing, and prototype application of a new capability to couple atmospheric models of different spatial and temporal scales with a state-of-the-science vegetation-fuel combustion model and a GIS[1]-based analysis system. The research addressed the complex, multi-scale interactions of atmospheric processes, combustion, and vegetative fuel conditions, using a suite of models to simulate their impact on wildfire behavior in areas of complex terrain. During the course of the project, we made substantial progress toward the implementation of a world-class modeling system that could be used as a tool for wildfire risk assessment, wildfire consequence analysis, wildfire suppression planning, fuels management, firefighter training, and public fire-safety education. With one additional year of funding we would have been able conduct combined modeling and field experiments to evaluate the models' capability to *predict* the behavior of prescribed burns before they are ignited. Because of its investment in this LDRD project, LLNL is very close to having a new core capability -- likely the world's most generally applicable, most scientifically sound, and most respected wildfire simulation system.

BACKGROUND AND PURPOSE

Wildfire: An Enduring National Problem

Wildfires are a threat to human life and property; yet they are unavoidable natural phenomena and are necessary for the healthy functioning and evolution of forest and grassland ecosystems. The magnitude of the wildfire problem is apparent from the statistics of the 2000 fire season. In that year, wildfires burned more than 6.8 million acres of public and private lands, resulting in loss of property, damage to resources, and disruption of community services. Many of these fires burned in the urban-wildland interface and exceeded local fire-suppression capabilities. In May 2000 a prescribed burn, gone awry, caused a devastating wildfire that swept through the area of Los Alamos National Laboratory. Later in the year, wildfires threatened DOE's Hanford and Idaho Falls facilities. For several weeks during the summer of 2000, the daily cost of fire suppression efforts exceeded 15 million dollars. More recently, the destructive wildfires in Colorado, Arizona, and California in the summer of 2002 were also searing reminders of the wildfire threat.

The wildfire problem has been exacerbated by over 100 years of "successful" fire suppression activities that allowed the development of unhealthy, unnaturally crowded forests and an unprecedented, dangerous accumulation of dead and live fuels in forests and grasslands. Years of intensive prescribed burning will be required to restore these areas to healthy conditions. The danger to human life and to costly infrastructure has been greatly increased by mass migrations of populations from cities to the outlying urban-wildland interface, where homes are nestled within decadent fuel accumulations. Particularly in these areas, wildfire could be a simple, inexpensive, and horrifically effective weapon for terrorists. Several of our wildfire management

[1] GIS: Geographical Information System

collaborators have suggested that we model the behavior of fires ignited by arsonists-terrorists in the urban-wildland interface.

Many areas of California have high potentials for disastrous wildfires. The Los Angeles County Fire Department, the Nation's largest fire department, has strongly endorsed our research because of its relevance to their major wildfire concerns. Even closer to home, the highly developed area of the East Bay Hills is one of the most severe fire risk areas in the United States. More than 3,542 homes have been lost to major wildfires in that area. In fact, 39% of the residences destroyed in California's 30 worst wildfires were in the East Bay Hills. The $1.7 billion Oakland-Berkeley 1991 wildfire claimed 25 lives, and was the nation's fifth most costly catastrophe[2]. Through the Hills Emergency Forum (HEF), we worked closely with the major East Bay fire agencies and concerned stakeholders, including three city governments (Oakland, Berkeley, and El Cerrito), the East Bay Regional Park District (EBRPD), the East Bay Municipal Utilities District (EBMUD), UC Berkeley, Lawrence Berkeley National Laboratory, and the California Department of Forestry and Fire Protection (CDF). HEF even passed a resolution endorsing this research project.

The Challenging Science of Wildfire Behavior

For over fifty years, attempts have been made to understand and predict the behavior (intensity, propagation speed and direction, and modes of spread) of wildfires. However, the factors that determine wildfire behavior are complex; they include fuel characteristics and configurations, chemical kinetics, balances between different modes of heat transfer, topography, and fire/atmosphere interactions. Despite these complexities, the U.S. Forest Service and other fire management agencies use relatively simple fire behavior models that are based on empirical and statistical data. These "point-functional" models use look-up tables to estimate burn rates (not self-determined propagation rates) based on single-point-values of fuel type (typically 13 choices), wind speed (a constant scalar), and terrain slope (not three-dimensional shape) specified by the user. Although these simple models might be acceptable for certain limited applications, they do not account for the many important nonlinear, interacting physical processes that determine the behavior of actual wildfires. For example, these models cannot simulate changes in fire behavior due to fire-driven perturbations in the wind field; they cannot simulate the effects of complex topographical features on fire behavior nor on the wind (and, in turn, on the fire); and they cannot simulate the convective- and radiative preheating, drying, and pyrolization of fuels by an advancing fire front.

Early Research by our Collaborators at Los Alamos National Laboratory

Over a period of approximately four years, a team of scientists at Los Alamos National Laboratory (LANL) developed a fully-physics based, small-spatial-domain fire model that uses a transport approach to simulate wildfire behavior, including fire propagation rate. Rodman Linn accomplished the initial research and model development for his doctoral dissertation. His high-resolution fire-behavior model, FIRETEC, predicts fire spread based on a fundamental treatment of combustion, turbulence, and other physical processes. The model can represent fires in environments with heterogeneous fuel distributions and complex terrain. Using typical spatial resolutions of 1 to 10 meters, FIRETEC accounts for the microscopic details of a fire by dividing quantities (fuel, airflow, temperature, and gas concentrations) into mean and fluctuating parts, similar to techniques used in traditional turbulence modeling. The model represents fuel in three dimensions, includes convective- and radiative heat transport, accounts for phase changes, and tracks the depletion of fuels and oxygen during combustion.

In order to account for the fire-atmosphere feedback mechanisms in the immediate vicinity of fires, the LANL wildfire team imbedded FIRETEC within the HIGRAD (the HIgh GRADient flow-solver) model (Reisner et al. 2000). HIGRAD solves the compressible form of the Navier Stokes equations in a generalized coordinate system that allows for variable horizontal and vertical resolution. To overcome the time-step restrictions related to the speed of sound, HIGRAD employs two numerical techniques, the method of averaging and the Newton-Krylov technique. These two techniques are completely different in concept, one being explicit and the other

[2] Exceeded only by hurricanes Andrew and Hugo, the 1993 East Coast floods, and the Northridge earthquake

implicit; however, used together they allow HIGRAD to be computationally robust over a large parameter space. Because of the models' interactive capability, HIGRAD/FIRETEC can simulate the driving mechanisms of fire propagation in ways that far exceed the capabilities of empirically based fire models like those presently in widespread use by the wildfire community. The LANL wildfire team tested the HIGRAD/FIRETEC system for numerous idealized cases, and successfully simulated the behavior of the 1994 South Canyon, CO fire (that claimed the lives of 14 firefighters) and the 1996 Coral Canyon (CA) fire (that seriously injured one firefighter). It is important to note that, for both of these simulations, the fires were of short duration (approximately 30 minutes), the spatial domain was small (1 - 2 km), and the initial and boundary atmospheric conditions for HIGRAD were specified as spatially homogeneous, constant values.

LDRD-SPONSORED RESEARCH AT LAWRENCE LIVERMORE NATIONAL LABORATORY

Accounting for the Effects of Mesoscale Weather on Fine-Scale Processes

At the time this project began, HIGRAD/FIRETEC was (and still is) almost certainly, the most advanced wildfire model in existence. However additional research was necessary before the model could achieve its full potential. More simulations of well-documented fires were necessary to adequately validate the model. A representation of the process of firespread by "spotting" (ignitions caused by showers of embers) was needed[3] (short-range spotting was already treated implicitly). Additional applications could be realized by coupling the wildfire model in some way with a detailed structural fire model.[4] *However, the one enhancement that was essential for almost all applications of the wildfire model was to provide an appropriate coupling of HIGRAD/FIRETEC to an atmospheric model that accurately represents mesoscale weather processes.*

Because HIGRAD/FIRETEC uses fine-spatial-scale resolution (1 to 10 meters) and is computationally intensive, it is limited to simulations over relatively small spatial domains (typically one to a few kilometers). Although this domain size is adequate for many fire simulation applications, it is not large enough to provide a descriptive, dynamically consistent representation of the changing regional atmospheric environments within which wildfires burn (i.e., the initial and boundary conditions for HIGRAD/FIRETEC). For example, HIGRAD cannot represent weather features such as cold fronts, high- and low- pressure systems, and precipitation that develop over much larger geographical areas and have strong impacts on the local weather and fire behavior. This limitation applies equally to forensic simulations of historical fires, simulations of hypothetical fires, and predictions of future fire behavior.

In order to overcome the limitation described above, we directed our efforts toward the goal of using COAMPS (the Naval Research Laboratory's Coupled Ocean-Atmosphere Mesoscale Prediction System) to provide the regional atmospheric environment within which HIGRAD/FIRETEC simulations can be run. COAMPS consists of an atmospheric data assimilation system, a nonhydrostatic forecast model, and a hydrostatic ocean model, and is designed to simulate a wide spatial and temporal range of atmospheric phenomena. The atmospheric forecast model uses the time-splitting technique to minimize the time-step restrictions related to the speed of sound in the nonhydrostatic, compressible model. COAMPS is formulated in terrain-following coordinates, which are advantageous for atmospheric simulations over rugged terrain. It has a nested-grid capability, tracer calculation, and complete model physics, such as parameterizations of subgrid-scale turbulence mixing, surface momentum and heat fluxes, cumulus cloud processes, explicit moist cloud processes, and shortwave and longwave radiation. COAMPS is fully operational, is relocatable to any location on Earth, and is run twice daily by NARAC for each of two geographic regions in the United States. NARAC runs COAMPS with typical horizontal resolution/domain dimensions of 4.0/320.0 km, 12.0/960.0 km, and 36.0/2880.0 km. It is possible, but not typical, for COAMPS to use horizontal resolutions as small as the order of 100 m.

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[3] When this project's funding terminated, we were collaborating with Dr. Rodman Linn at LANL and Dr. Patrick Pagni at UC Berkeley to add a spotting physics module to HIGRAD/FIRETEC. This effort was being coordinated through the UC Department of Agriculture and Natural Resources (DANR) Fire Workgroup, of which Drs. Bradley and Molenkamp are active members.

[4] Also through the DANR Fire Workgroup, when funding terminated we were working with Drs. Ronald Rehm and David Evans of the National Institute of Standards and Technology (NIST), Gaithersburg, MD, to explore linking our model with their physics-based model of structural fire ignition and burning.

General Methodology

The issues we investigated in this exploratory research project can be grouped into two general categories: numerical issues and physical issues (although for some issues, the distinction between the two becomes a bit fuzzy). To address the *numerical issues* related to inter-scale model coupling, we used numerical analysis techniques, scale analyses, and sensitivity studies to gain insight into:

¥ the range of spatial and temporal scales within which the models' numerics most appropriately interface, with balanced emphasis on implications for accuracy and computational speed.

¥ the impacts of numerical aliasing and wave reflections.

¥ whether the models must be fully interactive, both up- and down- scale, in order to achieve sufficiently accurate results.

To address the *physics issues* related to inter-scale model coupling, we used scale analyses, sensitivity studies, idealized case studies, and comparisons of model simulations with observations to determine:

¥ the spatial-resolution limits at which representation of physical processes by COAMPS (at its fine-scale limit) and by HIGRAD (at its coarse-scale limit) becomes inappropriate. The goal was to determine "where", in resolution space, to couple the models. Our expectation was that there *is* a spatial scale overlap where COAMPS and HIGRAD are both applicable.

¥ if the up-scale (HIGRAD/FIRETEC to COAMPS) transfer of thermal energy from simulated fires significantly impacts the thermal and dynamical processes resolved on the innermost COAMPS grid, and, in turn, cycles back downscale to affect fire behavior

Sensitivity Studies

A major portion of our investigation of how to most appropriately couple HIGRAD/FIRETEC with COAMPS involved numerous simulations of wildfire behavior in Tunnel Canyon (near the Caldecott Tunnel). For many of these simulations, we started with the atmospheric conditions for 11:00 a.m. PDT (1900 UTC), October 20, 1991. The time, date, and location of these fire simulations correspond to the start of the catastrophic 1991 East Bay Hills fire. It is interesting to note that the simulation of historical fires, such as we accomplished in this project, adds yet another layer of challenge above that which would be encountered simulating fires in near-real time -- namely the forensic reconstruction of high-resolution historical weather conditions. To provide the initial conditions and time-dependent boundary conditions for COAMPS, we used global reanalysis data for 20 Oct 1991 from the European Center for Medium Range Weather Forecasting (ECMWF)[5]. The horizontal resolution of the reanalysis data is one degree in latitude and longitude.

During the course of the project, we investigated various combinations of nesting levels and spatial resolution for the COAMPS model. Our finest-resolution COAMPS run employed six levels of grid nesting with horizontal resolutions of 36.0km, 12.0 km, 4.0 km, 1.33 km, 443 m, and 148 m. The simulated atmospheric fields from the innermost COAMPS grid were used to provide the initial and boundary conditions for 10-meter-resolution HIGRAD atmospheric simulations, centered over Tunnel Canyon, with a horizontal domain size of 1.6 km square. After the HIGRAD simulations achieved quasi-steady-state, we provided an initial temperature pulse (typically 100...C above ambient temperature) to FIRETEC to ignite the fuel at the location where the fire started. One of the characteristics COAMPS that we became aware of was that, in general, COAMPS-simulated airflows over complex terrain do not achieve a truly steady-state condition. Transient flows, such as the shedding of eddies from ridgelines, were evident in many of our simulations.

[5] Details of this procedure are discussed in our FY2002 proposal.

Because it was necessary to learn how HIGRAD/FIRETEC simulations varied for different fuel types, fuel moisture contents, and atmospheric conditions, we conducted numerous sensitivity studies of fire behavior in Tunnel Canyon. We used a range of actual and hypothetical fuel types, including data from the wildland vegetation GIS layer, developed by the Applied Environmental Geographic Information Laboratory at UC Berkeley. We also created hypothetical uniform distributions of grasses, eucalyptus trees, and coyote bushes (the latter was suggested by Fire Chief Dennis Rein of the East Bay Regional Park District as being fairly representative of the fuel in Tunnel Canyon on October 20, 1991). For most of these simulations, the state of the regional atmosphere was represented by the COAMPS simulation described above; in addition, some simulations used modified atmospheric conditions (wind speed, wind direction, atmospheric stratification, etc.)

Because of the large number of sensitivity studies that we accomplished, it is not practical to describe each of them in detail. We examined fire behavior sensitivity to model resolutions, model time-step, model domain size, wind speed, wind direction, atmospheric stability, ignition location, ignition time, area of ignition site, fuel density, fuel shape, fuel moisture content, the impact of roads, etc. Three examples will be presented here.

The results of one of our wind speed sensitivity studies are shown in Figure 1. For this study, we conducted three simulations of hypothetical fires in a uniform distribution of eucalyptus trees in Tunnel Canyon, all using the wind *direction* (from 40...) simulated by COAMPS for 20 Oct 1991. Figure 1(b) shows the percentage of fuel consumed after 15 minutes of simulated time, using the same wind *speed* predicted by COAMPS. Figures 1(a) and 1(c) show corresponding simulations, but with the wind speed scaled by factors of 0.2 and 2.0, respectively. The strong impact of wind speed on fire propagation rate is evident, and underscores the importance of providing accurate initial and boundary conditions for HIGRAD/FIRETEC. Another interesting feature of these simulations is that Figures 1(b) and 1(c) suggest that the interacting fire/atmospheric models properly capture the well known "chimney" effect, by which fires selectively progress upward through gullies.

Figure 2 shows the results of a sensitivity experiment designed to examine the effects on fire behavior of different fuel types having the same moisture content. The percent of fuel consumption ten minutes after ignition is shown for three hypothetical fires in Tunnel Canyon. The initializing regional wind is 10 m/s from 40¡, as simulated by COAMPS for 20 Oct 1991. Figure 2(a) is for the Hills Emergency Forum's (HEF) 30-meter-resolution vegetative fuel survey of 1993, 2(b) is for a hypothetical, uniform distribution of eucalyptus trees, and Figure 2(c) is for a hypothetical uniform distribution of coyote bush. The fire in the HEF fuel (largely grasses) and in the coyote bush spreads more rapidly, but the fire in the eucalyptus trees burns longer, because of the much higher fuel loading. The more complex burn pattern for the HEF fuel types, particularly near the leading edges of the fire fronts, is largely due to the heterogeneous distribution of mixed fuel types. Once again, note the "chimney effect" of the gullies in Fig. 2(b).

We also examined the sensitivity of fire behavior simulations to small displacements of the ignition location. We learned that ignition point displacements of 100 m or even less (e.g., on one side of a gully, in the center of the gully, and on the other side of the gully) make a significant difference in the simulated fire propagation. These results suggested that we needed precise coordinates for the ignition point of the 1991 Tunnel Canyon fire, so we conducted a GPS survey of the site. With assistance from Bill Nichols of the East Bay Regional Park District Fire Department (who was on-scene when the 1991 fire started) and Jim Brunk (LLNL GPS expert), we measured very accurate coordinates of the exact ignition locations for the 20 Oct 1991 wildfire, and also for its predecessor fire on 19 Oct 1991[6]. According to Bill Nichols, this was the first time the ignition locations had been surveyed.

Up-Scale Thermal Feedback Study

We performed exploratory sensitivity studies to examine the COAMPS-simulated ambient wind response to the heat released from a fire. In order to simulate the effects of a fire in a controlled experiment, artificial heating was added to the COAMPS sub-surface temperature, providing a flux of sensible heat from the ground surface into the atmosphere. Specifically, we added a positive temperature perturbation to the "deep" soil temperature in

[6] Residual embers from the 19 October 1991 fire were the ignition source for the catastrophic 20 October 1991 fire.

order to provide a constant heat flux at the surface. The perturbation was a bell-shaped function ("witch of agnesi") in both the x (west-to-east) and y (south-to-north) directions, with a maximum value of 50...C at the center. The half-widths of the heating function were 5 grid intervals (710 meters) in the x-direction, and 10 grid intervals (1418 meters) in the y-direction. The prescribed heat source was elongated in the y-direction so that it would lie along the west side of the hills, approximately corresponding to the initial burn area of the 1991 Tunnel Canyon fire.

The results of a thermal feedback simulation are shown in Figure 3, where the heating source is centered in the domain (i.e. at the origin of the axes). The results from the simulation without heating are displayed on the left, and those from the simulation with heating are on the right. The dotted white contour lines indicate topography. The labeled color contours indicate the magnitude of the u-component (i.e., west-to-east component) of the near-surface wind velocity. Increased circulation is expected to develop near locations where the temperature gradient is greatest. As can be seen in the figure, the circulation is increased with heating; this effect is most evident in the relative strengths of the maxima to the southwest of the center of heating, located at (x,y) coordinates (-3.0,-2.) in the figure, and to the east at (4.,-0.5). There is also a relative minimum, or acceleration towards the heating at (2.5,-0.5). This flow could result from a descending branch of induced circulation; however, caution must be exercise in interpreting this result, because the (2.5,-0.5) location is close to the lateral boundary.

The acceleration towards the increased heating from the southwest is along the shoreline of the San Francisco Bay, where the combination of forcing due to the heating, and reduction of drag force over the water is greatest. The stronger dipole to the east is also evidence of increased circulation in the simulation with the additional heating. Additional studies will be required to develop general conclusions regarding the impact of this up-scale thermal forcing effect and to determine if it needs to be represented in the COAMPS model.

The LDRD Project's Final Simulations of the 1991 Oakland Hills Wildfire

In our final and most accurate series of simulations, we used the GPS coordinates of the 20 Oct 1991 ignition location to specify the ignition point in the model. We specified the fuel as a uniform distribution of coyote bush with 10% moisture content, based on suggestions from Dennis Rein, the East Bay Regional Park District (EBRPD) Fire Chief, who was familiar with the vegetation fuel conditions before the fire and also was involved in fighting it. We also benefited from knowledge acquired in meetings with other fire management experts, such as Chief Donald Matthews of the Oakland Fire Department and Bill Nichols of the EBRPD, both of whom witnessed the early stages of the fire. We set the fuel loading to zero in the burn scar from the fire on 19 Oct 1991 and also on streets and roads in the area. We used the COAMPS data to specify the initial and boundary conditions for HIGRAD/FIRETEC. This simulation, which was described by the Chief Reg Garcia of the Berkeley Fire Department as "just like the real thing", is shown in Figure 4 (sequence of 200...C three-dimensional temperature contours) and in Figure 5 (sequence of percent-fuel-burned contours). One of the more convincing features of this simulation, that is much more apparent in animated sequences, is that the fire progresses around the burn scar and up the slope, then reverses direction, comes back down the slope, and rapidly spreads southwestward and toward the Caldecott Tunnel. According to Chief Garcia, that is how the actual fire behaved.

As mentioned previously, one of the unique capabilities of this wildfire modeling system is that the model accounts for the important two-way interactions between the fire and the atmosphere. These interactions can be decisive in determining wildfire behavior, yet they are not represented by the empirical models currently used by fire management agencies. The strong impact of the fire on the close-in near-surface airflow pattern for the Tunnel Canyon fire is evident in Figure 6. After only 90 seconds, the fire has significantly altered the wind field. This altered wind field changes the speed and direction of fire progression, which, in turn, further modifies the wind.

Advances in GIS-Based Consequence Analysis

In parallel to our modeling efforts, our GIS team members developed procedures for analyzing the results of our wildfire simulations in terms of human and economic consequences. Using our percent-of-fuel-consumed predictions as a GIS layer, we have been able to analyze and display important geographical relationships, including distance to nearest fire station, impact on electrical power transmission lines, number of individual threatened, specific land parcels threatened (including street address), and even the percentage of vegetation that is consumed by fire (as a function of time) on specific land parcels. Other GIS analyses are possible, including the blockage of escape routes as fires pass over roads. Figure 7(b) is an example of the combined wildfire model/GIS capability that we developed.

ADDITIONAL ACCOMPLISHMENTS

Simulation of Fire Behavior in Claremont Canyon

We accomplished an initial, exploratory simulation of wildfire behavior in Claremont Canyon, using the same weather conditions as for the time of the Tunnel Canyon fire. In the future we hope to use the models to evaluate the effectiveness of fuel breaks and other vegetation management techniques in Claremont Canyon. We have been working with members of the East Bay fire management community to plan specific case studies. These simulations will not only help us further understand and improve the model, but they will also provide valuable information for numerous local agencies that have provided us with extremely valuable cooperation. If additional funding becomes available in the future, we might also simulate fire behavior in Strawberry Canyon, the site of LBNL, the Lawrence Hall of Science, and a portion of the UC Berkeley campus.

Formed and Led an Interagency, Interdisciplinary Wildfire Physics Research Consortium

Because of the capabilities that we developed during this LDRD project, the UC Department of Agriculture and Natural Resources (DANR) Fire Workgroup requested that DANR sponsor a series of workshops to explore the possibility of integrating diverse, state-of-the-science, physics-based modeling capabilities from various UC and government organizations in order to develop a world-class fire behavior simulation capability for the wildland-urban interface. The LLNL/LANL wildfire model will be a centerpiece for this effort.

The first workshop was held in October 2002 at UC's Blodgett Forest Research Station, and resulted in the formation of the Wildland-Urban Interface (WUI) Fire Physics Group. The Group has approximately 25 member scientists from a wide range of organization. A second workshop is scheduled for Feb 27 and 28, 2003. The workshops are emphasizing the development of collaborative research efforts and the identification of potential funding sources.

The Wildland-Urban Fire Physics Group Workshops have three main goals:

¥ Foster the exchange of information and ideas between leading scientists who are engaged in fire behavior research. Much of this information is new and unpublished.

¥ Encourage the integration of existing and developing fire simulation capabilities into a cohesive, community fire behavior simulation model, and

- Explore means of acquiring major funding to support a collaborative research and development effort with the end goal of realizing an operational fire simulation system

The success of the workshop and the strength of the newly formed WUI Fire Physics Group lies in the richness of the interagency, interdisciplinary capabilities of the participants and in their demonstrated capability to work together effectively. The scientific and technical capabilities of the WUI Fire Physics Work Group include:

¥ Ground-based characterization and mapping of vegetative fuels (in the field)

¥ Airborne, hyperspectral remote sensing of vegetation fuels (species typing, live-dead characterization)

¥ Ignition temperatures and combustion rates of live fuels

¥ Fine-scale laboratory studies and numerical simulations of combustion/fluid-dynamic interactions

- ¥ Development and evaluation of chemical kinetic mechanisms
- ¥ Laboratory studies and field experiments on structural fires
- ¥ Research on the impacts of specific structural components and materials (such as windows, decks, and roofing) on the ignition of structures
- ¥ Physics-based numerical modeling of structural fires
- ¥ Fire safety engineering science
- ¥ Prescribed burns
- ¥ Real-time, high temporal- and spatial-resolution imaging of wildfires from manned aircraft and unmanned aerospace vehicles
- ¥ Atmospheric dynamics
- ¥ High-resolution weather prediction models
- ¥ Wildfire physics
- ¥ Physics-based wildfire modeling, including two-way fire-atmosphere interactions
- ¥ Modeling the process of spotting (fire spread by wind-blown firebrands)
- ¥ Statistical evaluation of fire behavior model performance and uncertainty
- ¥ Geographical Information System (GIS) analysis

SUMMARY OF LDRD PROJECT DELIVERABLES: NEW CORE CAPABILITIES AND POTENTIAL GROWTH AREAS

Possible Now

Wildfire preparedness planning and education
The modeling system could be a powerful tool for community wildfire preparedness planning and for public education, by providing realistic simulations of historical and hypothetical future fires at specific locations, using high-resolution terrain, vegetation types, and weather conditions.

Vegetation management planning
Fire behavior simulations could be used to evaluate the implications of long-term wildland vegetation management options (thinning, planned burns, fuel breaks) for forests, brushlands, and grasslands.

Community Development Planning
The modeling system could be used as a long-term planning tool for community development, especially in the urban/wildland interface, to address questions such as where to locate new homes, infrastructure, greenbelts, open areas, and fuel breaks.

Possible Soon (Contingent upon adequate research and development funding)

Predictions for prescribed burns
In order to reduce the risks of prescribed burns getting out of control, the integrated fire/weather modeling system could provide predictions of fire behavior for prescribed burns before the fuel is ignited. Because they are planned far in advance, prescribed burns provide the best opportunity for model validation. The burn location, time, and ignition sequence are known before the burn occurs; the fuel type, fuel loading, and fuel moisture content are measured before the burn; the weather conditions are known; and the behavior of the fire can be documented. We have had several offers from fire management agencies (including EBRPD, EBMUD, CDF, USDA Forest Service, and the LLNL Fire Department) to participate in prescribe burn programs. With follow-on funding at the 1 - 2 FTE level, it is quite possible that we would be able to run the COAMPS/HIGRAD/FIRETEC system fast enough to predict the first 30 minutes of fire behavior for a prescribed burn.

Fire threat analysis
During periods of high fire risk, the modeling system could provide predictions of potential fire behavior for specific locations and future times of concern. This capability could have application to homeland security issues.

Firefighter training
Firefighters could improve their skills while remaining in a safe environment by using realistic simulations of wildfire scenarios to better understand how different weather conditions, terrain, and various suppression efforts affect fire behavior.

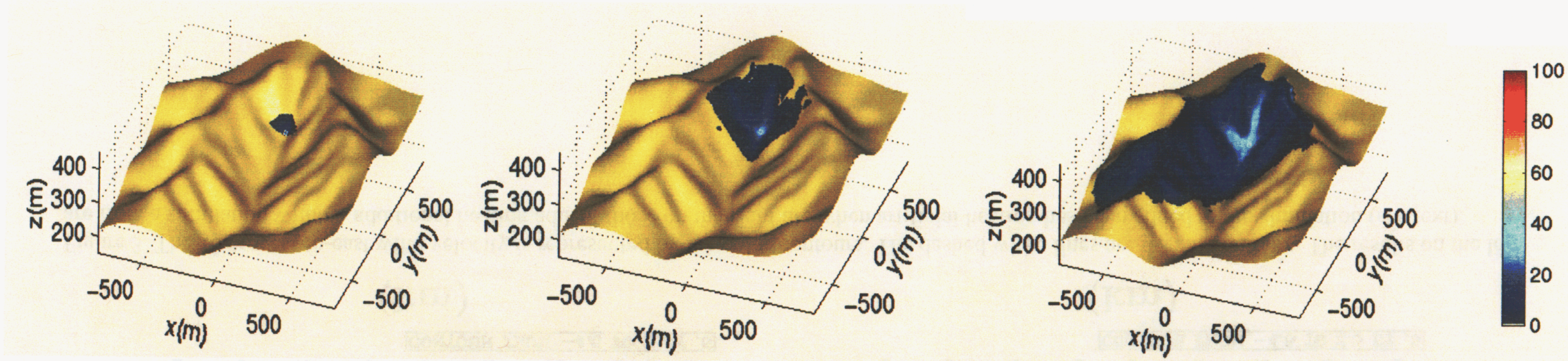
Future Applications (Contingent upon adequate research and development funding)

Real-time support for the firefighter
The modeling system could be a powerful decision-making tool that would provide real-time

- ¥ Predictions of wildfire and smoke behavior
- ¥ Simulations of firefighting operations, including predictive comparisons of the effectiveness of various firefighting options for specific fires
- ¥ Products and interactive support available over the Internet (and other communication modes) to control centers and first responders (NARAC already has developed this capability)

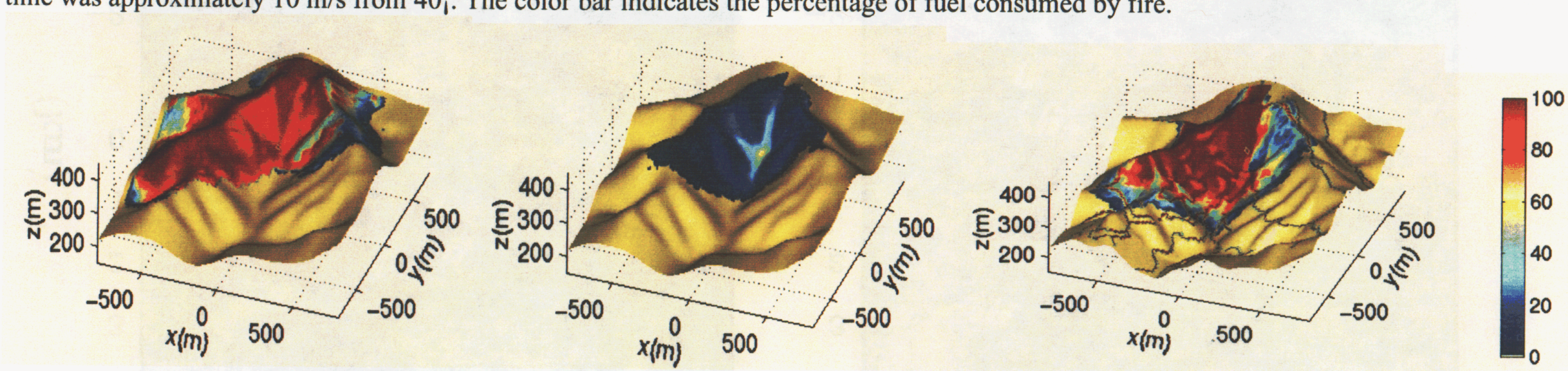
CONCLUDING REMARKS

The pioneering work accomplished in this LDRD project has succeeded not only in demonstrating the viability of greatly improved wildfire behavior prediction; it also has gained national attention, and has planted the concept of scientifically-based wildfire prediction within the consciousness of the wildfire management and wildfire science communities. Sometime within the next decade, an advanced, physics-based wildfire simulation capability, similar to the one co-developed at LANL and here at LLNL, *will* become an operational reality. If it is not this modeling system, then it very likely will have its conceptual and scientific roots in this system. Information provided by that future model will save lives, property, and natural resources. We thank the LLNL LDRD Program for enabling us to be a part of this historic and exciting and venture.



(a) (b) (c)

Figure 1. The effect of wind speed on simulated fuel consumption for a hypothetical, uniform stand of eucalyptus trees in Tunnel Canyon, six minutes after ignition. The initializing wind is from 40¡ (from the northeast; the x-axis points eastward and the y-axis points northward), with near-surface wind speeds of (a) 2 m/s, (b) 10 m/s, (c) 20 m/s. For the October 20, 1991 Tunnel Canyon wildfire, the regional-scale wind at ignition time was approximately 10 m/s from 40¡. The color bar indicates the percentage of fuel consumed by fire.



(a) (b) (c)

Figure 2. The effect of vegetation type on simulated fuel consumption for fires in Tunnel Canyon, ten minutes after ignition. The initializing wind is 10 m/s from 40¡. Fig. (a) is for the Hills Emergency Forum's 30-meter-resolution vegetative fuel survey of 1993. Fig. (b) is for a hypothetical, uniform distribution of eucalyptus trees. Fig (b) is for a uniform distribution of coyote bush. Note the "chimney effect" of the gullies in Fig. (b).

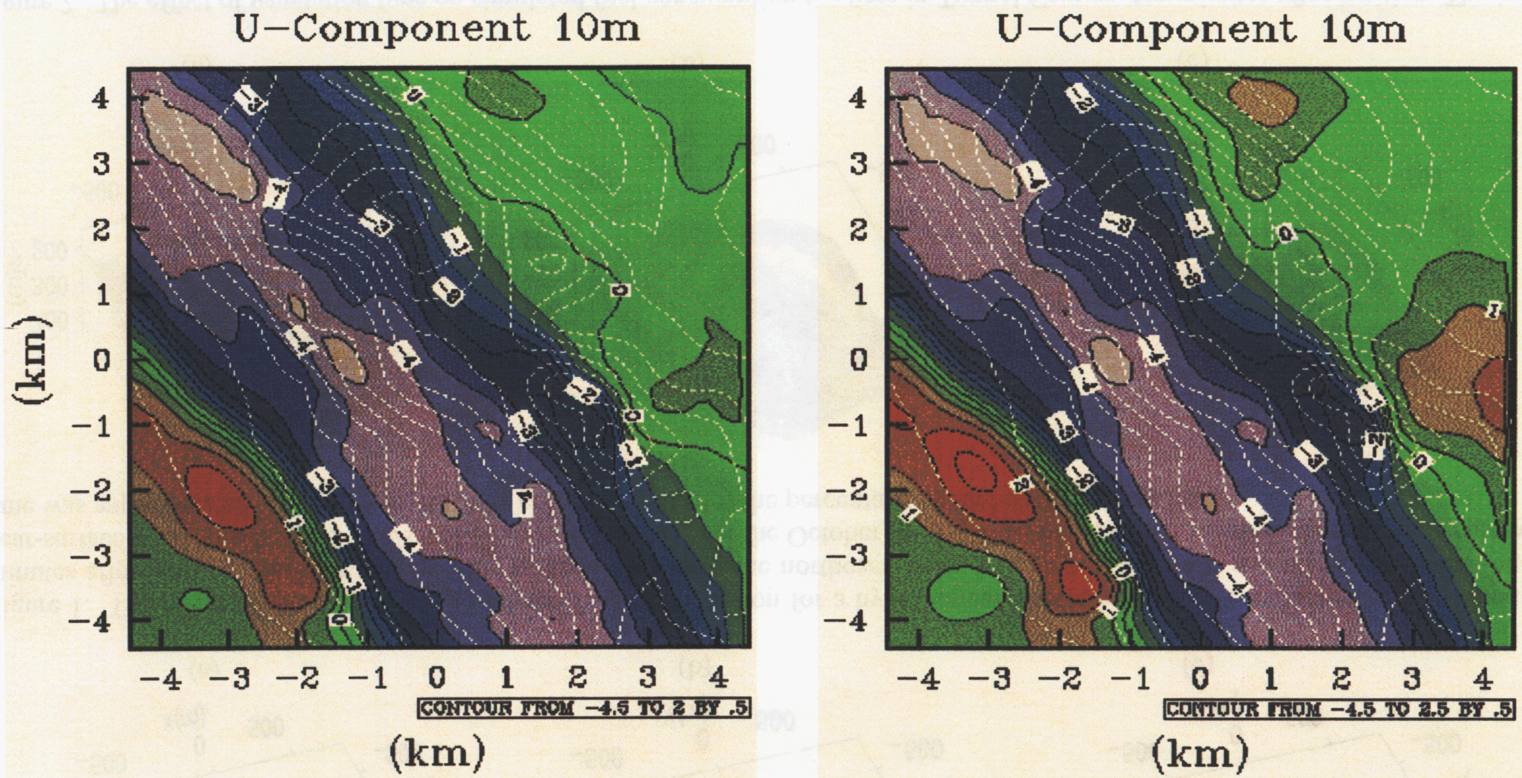


Figure 3. The 10 m west-to-east wind velocity is represented by the color contours. The dashed white lines are terrain contours. The results on the left are from a simulation with no additional heating added; those on the right are when artificial heating has been added to the simulation (see text).

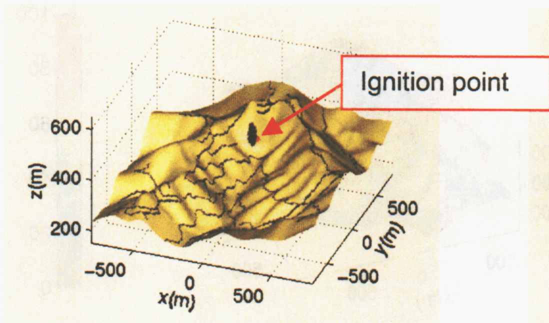


Fig. 4a. 10 seconds after ignition

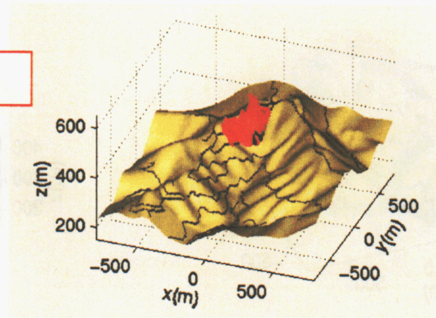


Fig. 4b. 2 minutes after ignition

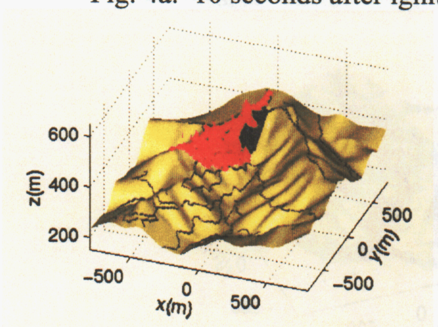


Fig. 4c. 4 minutes

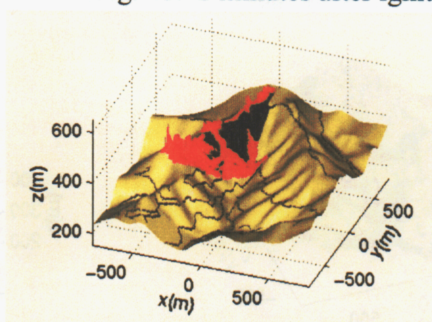


Fig. 4d. 6 minutes

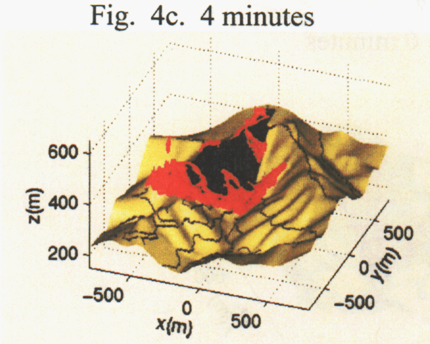


Fig. 4e. 8 minutes

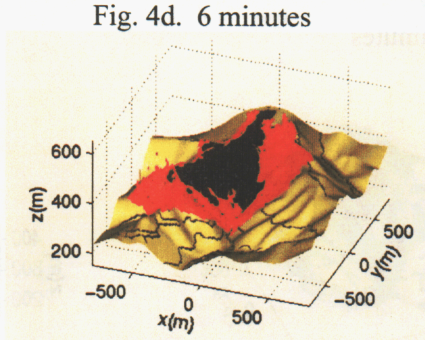


Fig. 4f. 10 minutes

Figure 4. Sequential 200¡C temperature contours for a simulated wildfire in uniformly distributed coyote bush in Tunnel Canyon. The atmospheric conditions are simulated for October 20, 1991. In Fig (a), note the burn scar from the fire that had not been fully extinguished on the previous day. The horizontal resolution for HIGRAD and FIRETEC is 10 meters.

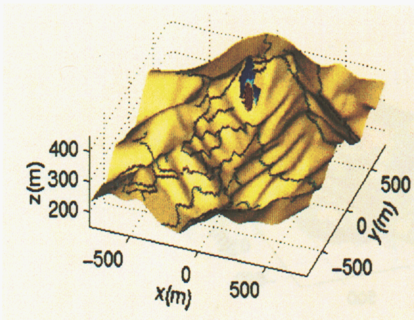


Fig. 5a. 1 minute after ignition

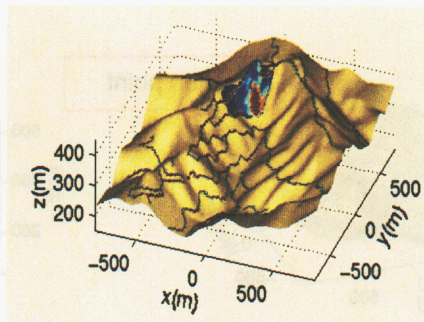
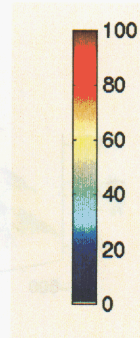


Fig. 5b. 2 minutes after ignition



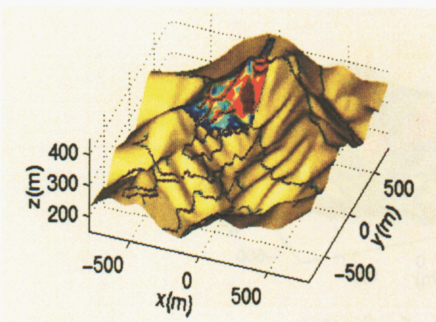


Fig. 5c. 4 minutes

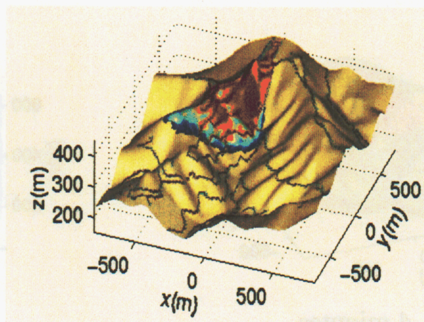


Fig. 5d. 6 minutes

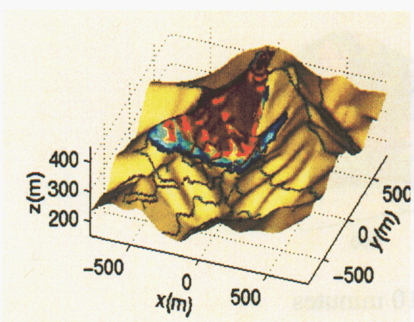


Fig. 5e. 8 minutes

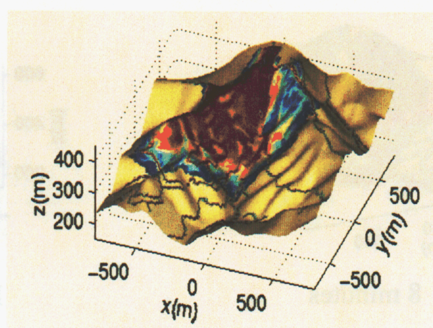


Fig. 5f. 10 minutes

Figure 5. Sequential fuel consumption analysis for the wildfire simulation shown in Figure 4. The color bar indicates the percentage of fuel consumed by fire.

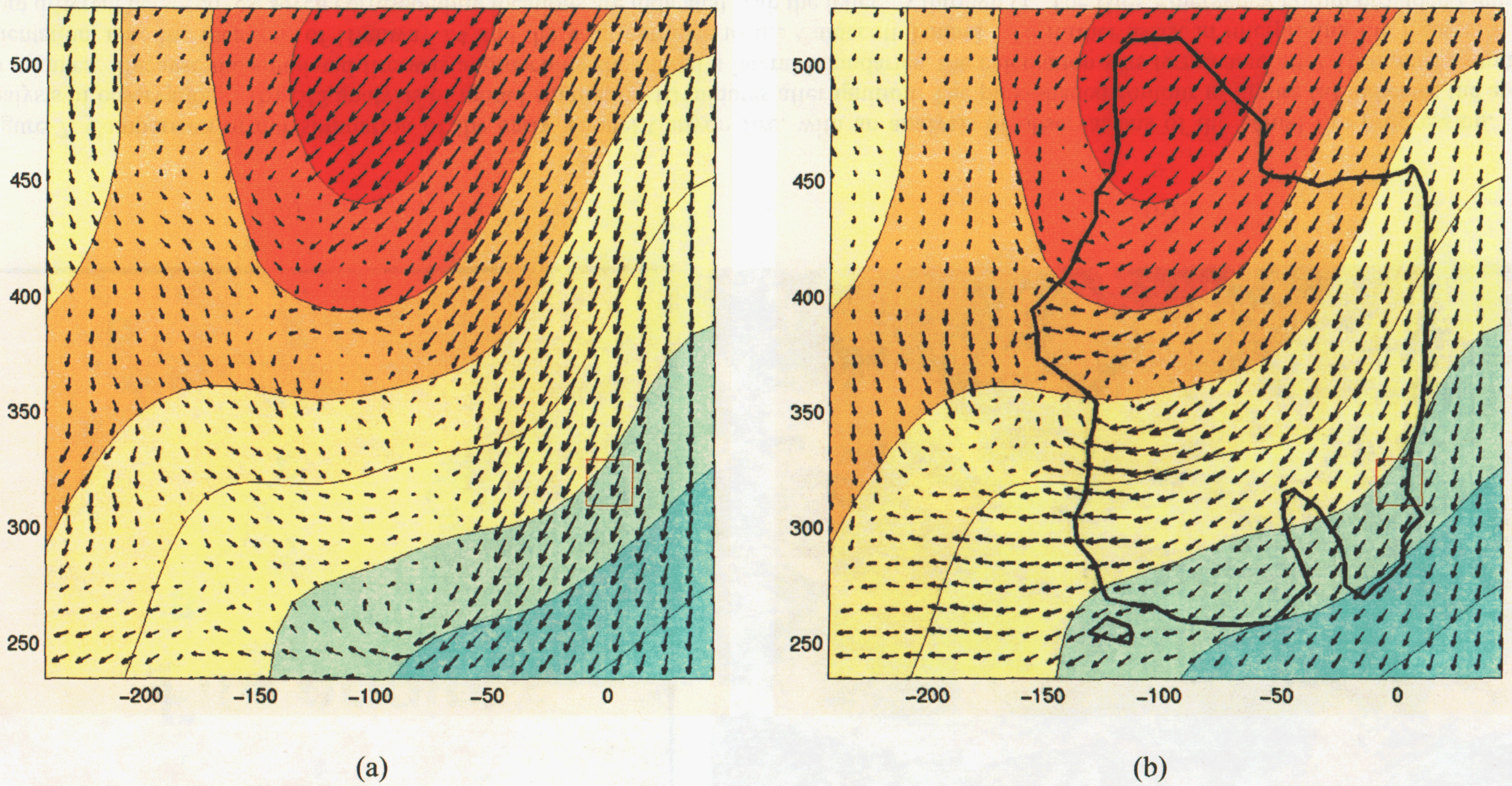
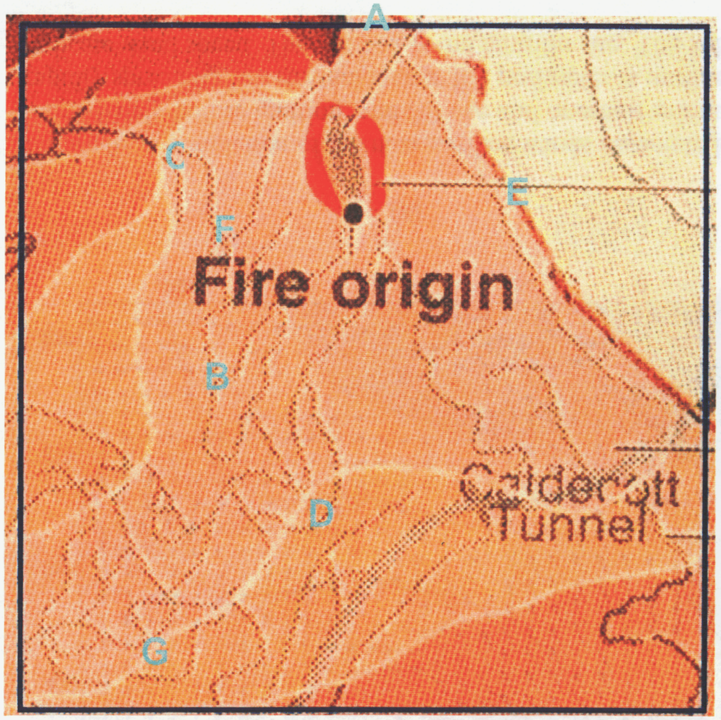
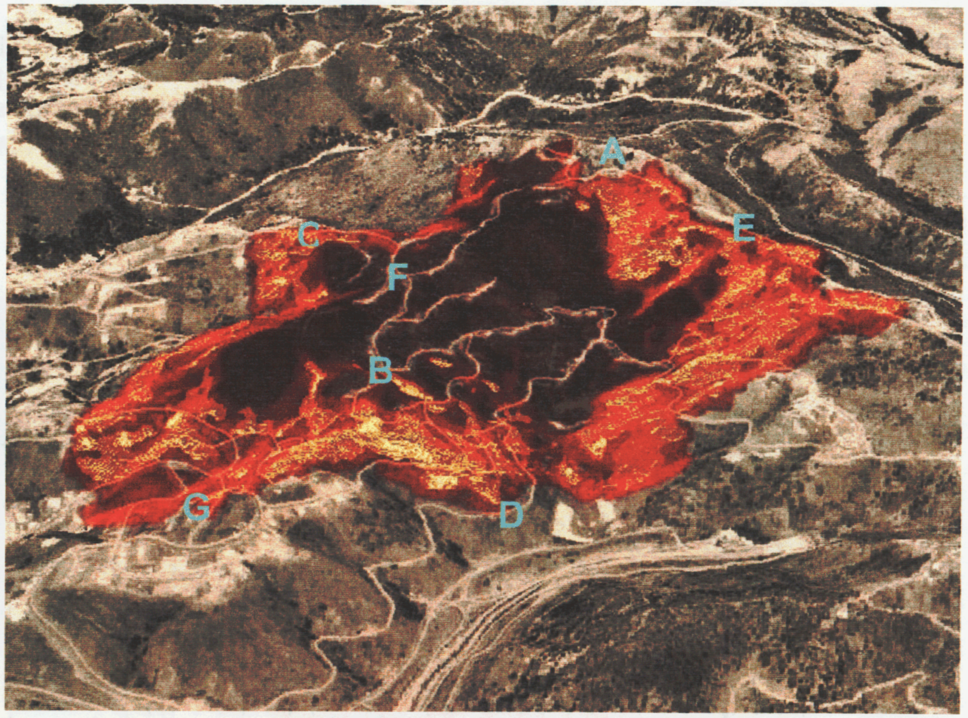


Figure 6. A simulation of the near-surface winds associated with the 1991 Tunnel Canyon wildfire, using 10-meter horizontal resolution, (a) immediately before ignition, and (b) one and one-half minutes after ignition, the wind speed and direction are significantly altered by the rapidly spreading fire (instantaneous fire perimeter is outlined in black). The arrow's directions indicate wind direction, and the arrows' lengths indicate wind speed. The red box is the ignition site. The solid colored contours depict terrain elevation, with red indicating the highest terrain.



(a)



(b)

Figure 7. Comparison of our simulation of the early Tunnel Canyon fire, with an analysis of observations of the actual fire progression. (a) Composite analysis of observations. (b) GIS analysis of model simulation 10 minutes after ignition. The pink-shaded contour in Figure (a) indicates the area burned after 15 minutes. Because the simulated fire was approaching the model's lateral boundaries, the calculation was terminated after 10 minutes simulated time. For orientation, note the locations of Highway 24 and the west entrance to the Caldecott Tunnel. To further assist in interpreting the figures, which are views from different perspectives, seven corresponding locations are indicated with the letters A through G. The Hills Emergency Forum provided Figure (a).